REPORT No. 575

INTERFERENCE OF WING AND FUSELAGE FROM TESTS OF 28 COMBINATIONS IN THE N. A. C. A. VARIABLE-DENSITY TUNNEL

By ALBERT SHERMAN
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73658—37

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By Albert Sherman

SUMMARY

Tests of 28 wing-fuselage combinations were made in the variable-density wind tunnel as a part of the wing-fuselage interference program being conducted therein and in addition to the 209 combinations previously reported in N. A. C. A. Report No. 540. These tests practically complete the study of combinations with a rectangular fuselage and continue the study of combinations with a round fuselage and a tapered wing.

INTRODUCTION

An extensive wing-fuselage interference investigation has been undertaken in the N. A. C. A. variable-density wind tunnel as the second phase of a general program designed to cover the problem of interference. A discussion of this program is included in reference 1, which presents the basic part of the wing-fuselage interference investigation and contains test results for 209 combinations.

The present paper is a continuation of reference 1 and presents the results for some 28 additional wing-fuselage combinations that were indicated by the program outlined therein. The present tests practically conclude the study of combinations with a rectangular fuselage and continue the study of combinations with a round fuselage and a tapered wing. Future reports will cover further phases of the wing-fuselage interference investigation.

MODELS AND TESTS

The models employed for the combinations tested herein were those used in reference 1; they are the N. A. C. A. 0012 and the N. A. C. A. 4412 rectangular wings, the tapered N. A. C. A. 0018 09 wing, the round- and rectangular-section fuselages, the 9-cylinder radial engine, and the engine cowling. Fillets were carefully made up of plaster of paris as required.

The tests were of connected combinations only, 28 in all (see table V and figs. 8 to 11), and covered the effect of vertical displacement of the airfoil from the fuselage axis, k/c (see reference 1), the effect of fillets on various wings in combinations with the rectangular fuselage, and the effect of fillets and of a cowled engine on round-fuselage, tapered-wing combinations for various vertical wing positions. The wings were set in combination at only one longitudinal location, $d/c=0$, and at zero incidence, $i_w=0$. (See figs. 1 to 7.) It should perhaps be mentioned here that the N. A. C. A. 4412 airfoil, because of its negative angle of zero lift, might be considered as having been at a positive angle of incidence, relative to the symmetrical airfoils.

The tests were run in the variable-density wind tunnel (reference 2) at a test Reynolds Number of approximately 3,100,000. In addition, values of maximum lift were obtained at a test Reynolds Number of approximately 1,400,000. The testing procedure and test precision, which are very much the same as for an airfoil, are fully described in reference 1. Since the tests of reference 1 were made, however, a small additional correction of less than -1 percent has been applied to the measurement of the dynamic pressure q as standard procedure to improve the precision of the results.

RESULTS

The test data are presented in the same manner as those of reference 1, in which the methods of analysis and presentation of the results are fully discussed.

Tables I and II present the characteristics of the wing and fuselage models separately (reference 1). Table III (continued from reference 1) presents the interference of the 28 wing-fuselage combinations. Table IV of reference 1 is not continued herein as no additional tests of disconnected combinations were made. Table V (continued from reference 1) presents the aerodynamic characteristics, combination descriptions, and profile diagrams of the combinations. In the present report, however, new values of the effective Reynolds Numbers at $C_{L_{max}}$ are given as a result of a new determination of the turbulence factor for the tunnel. The present turbulence factor for the variable-density tunnel is taken as 2.64, whereas a value of 2.4 was used in reference 1. The combinations in this report can be compared, however, with those in reference 1 on the basis of the test Reynolds Numbers, which remain the same.

Figures 1 to 7 show the polar characteristics of the interesting combinations investigated together with those of some combinations taken from reference 1 for comparison.

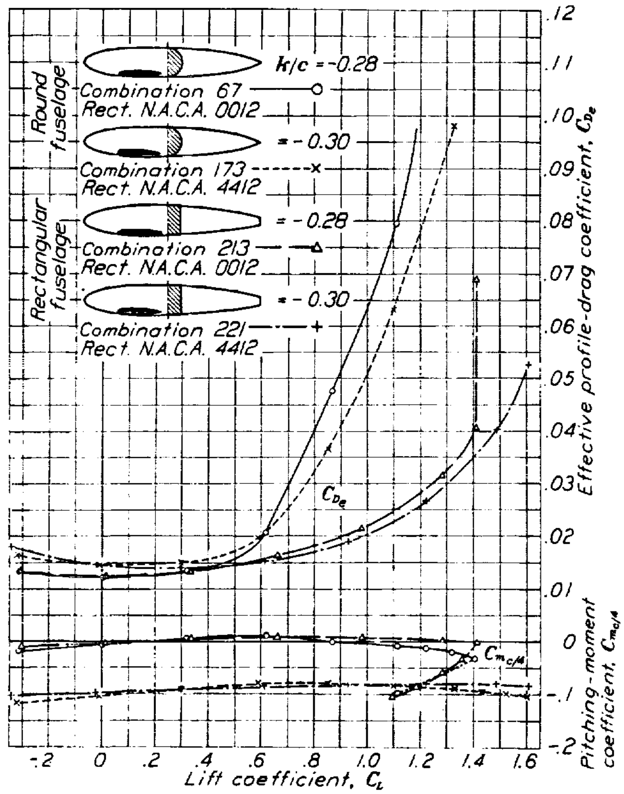


FIGURE 1.—Effect of fuselage section on wing-fuselage interference.

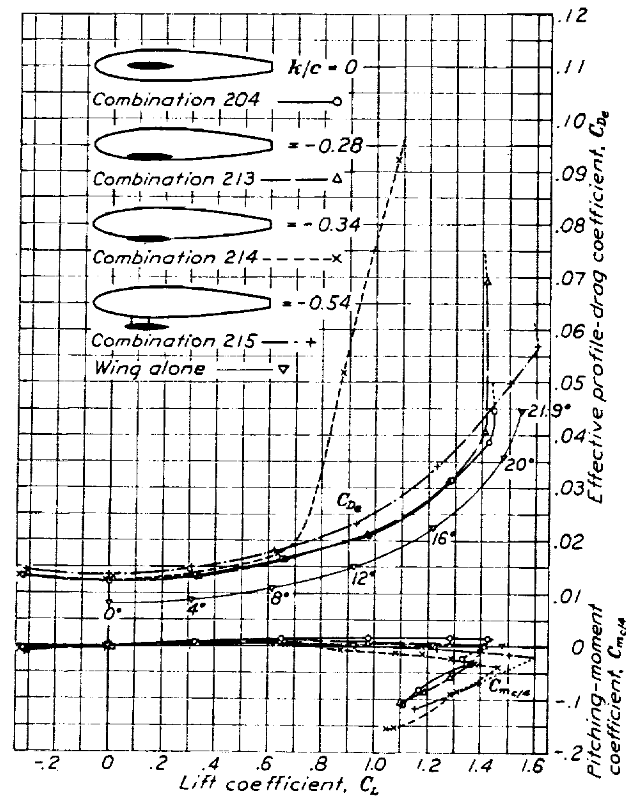


FIGURE 2.—Characteristics for various vertical wing positions. N. A. C. A. 0012 rectangular wing with rectangular fuselage.

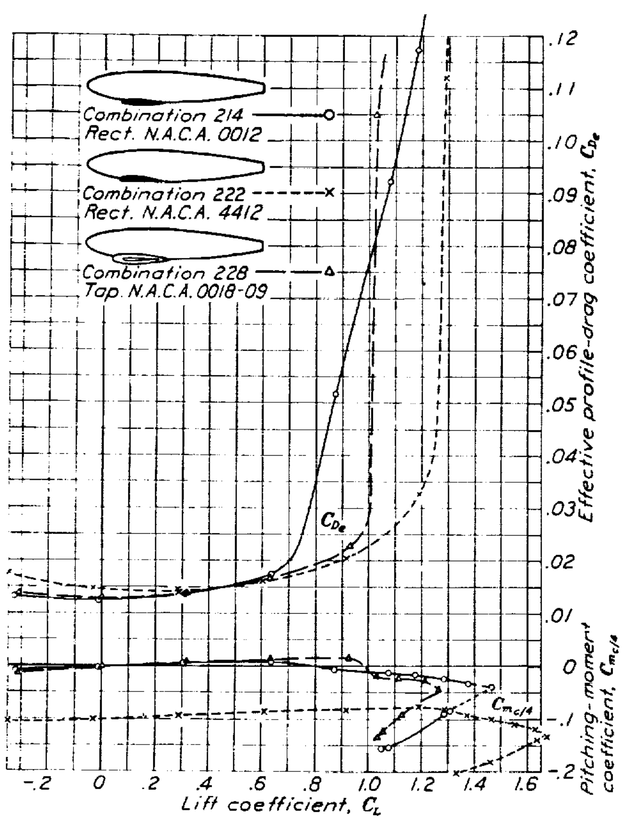


FIGURE 3.—Characteristics for various wing shapes with rectangular fuselage; $k/c=-0.34$.

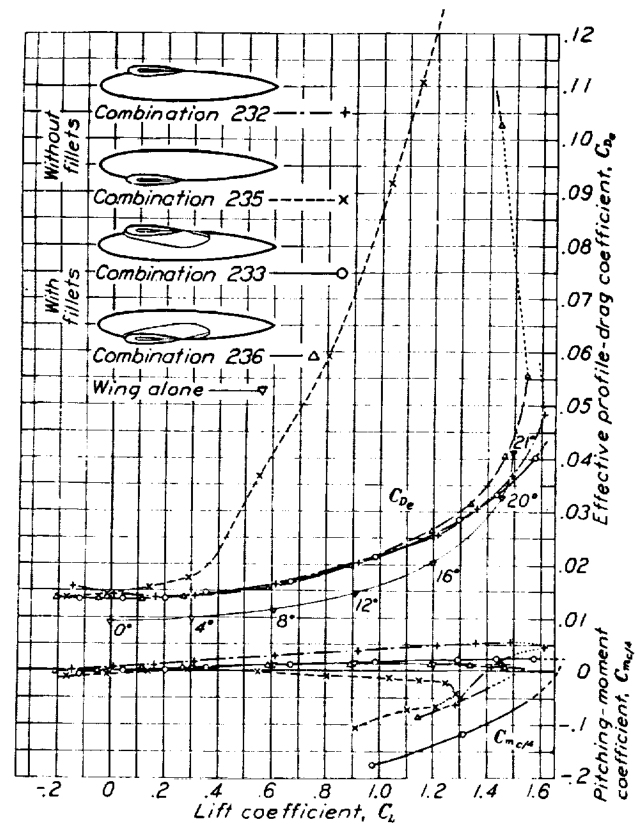


FIGURE 4.—Effect of fillets on tapered-wing, round-fuselage combinations; $k/c=\pm0.34$.

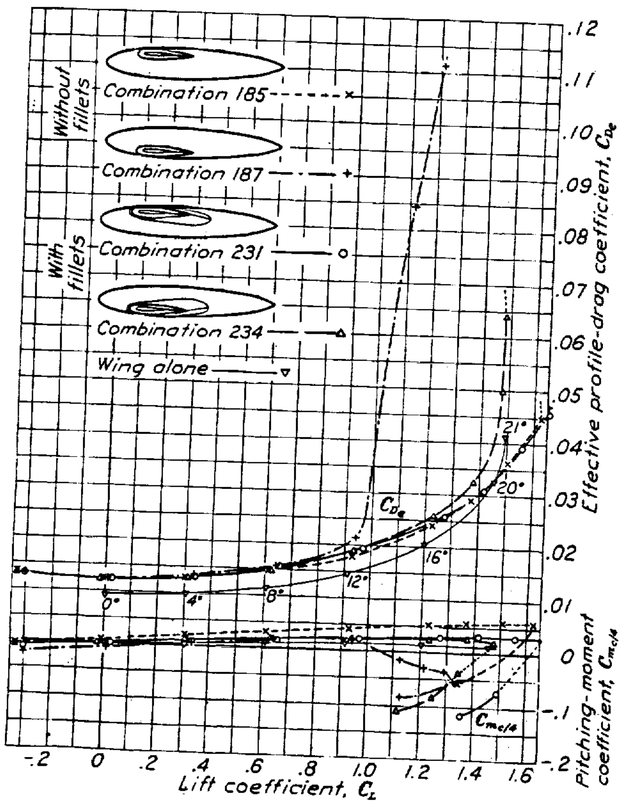


Figure 5.—Effect of fillets on tapered-wing, round-fuselage combinations; $k/c=\pm0.22$.

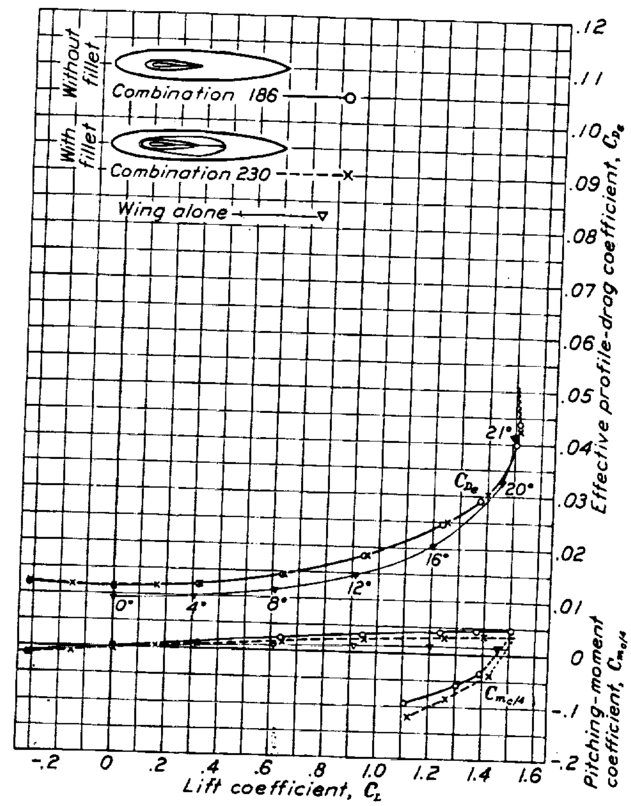


Figure 6.—Effect of fillets on tapered-wing, round-fuselage combinations; $k/c=0$.

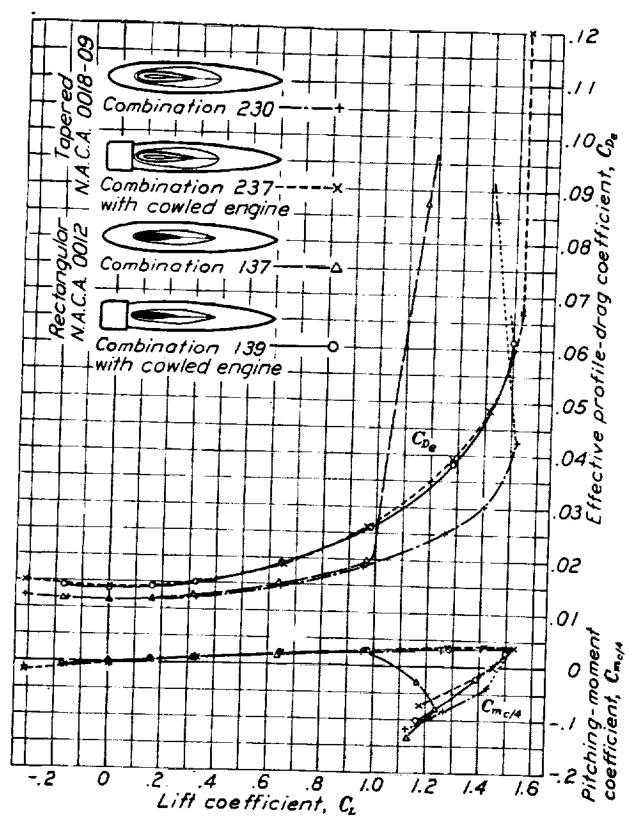


Figure 7.—Characteristics of cowled-engine, filleted combinations; $k/c=0$.

DISCUSSION

Combinations with rectangular-section fuselage.—It was shown in reference 1 that the rectangular-section fuselage had a higher minimum drag than the round-section fuselage and that its drag, moreover, increased much more rapidly with angle of attack (table II). It was also shown, however, that when in combination with a wing the rectangular fuselage produced only a slightly greater drag increase with angle of attack than did the round fuselage, so that in its case the drag *interference* was generally more favorable. (See tables II and III.)

Low-wing combinations with the rectangular fuselage had generally better wing-root junctures than corresponding unfilleted combinations with the round fuselage; there was less tendency to an early breakdown of the flow (see fig. 1), which is known as an "interference burble" (reference 1). Where an interference burble does occur for a combination with the round fuselage, substitution of the rectangular fuselage might result in a later-burbling combination having a drag almost as low as with the round fuselage and sometimes even lower (fig. 1).

Similar low-wing combinations with either fuselage showed approximately the same maximum lifts, but for midwing combinations with a rectangular wing the rectangular fuselage gave higher values.

Figure 2 shows the effect of the wing vertical position for the rectangular N. A. C. A. 0012 airfoil with the rectangular fuselage. As might be expected, there was little difference for combinations having the wing section wholly within the fuselage (tables III and V). The connected low-wing combination that exposed the leading edge of the wing exhibited an early flow breakdown but, surprisingly, no higher minimum drag than the others. The disconnected combination, in which no portion of the wing was shielded by the fuselage, had both a higher drag and higher maximum lift.

The rectangular fuselage had somewhat different interference when combined with differently shaped wings (table III). As previously shown in reference 1, the rectangular symmetrical N. A. C. A. 0012, the tapered symmetrical N. A. C. A. 0018–09, and the rectangular cambered N. A. C. A. 4412 wings were sensitive to the interference burble in the order named. This effect is very well demonstrated in figure 3, in which the three wings, combined in the only vertical position investigated that showed large interference, are compared. (See fig. 2.)

Fillets on rectangular-fuselage combinations had only a very small effect for the combinations investigated (tables III and V). Such a result was to be expected from the discussion in reference 1, which stated that fillets had only a small effect on combinations that were already fairly satisfactory.

Combinations with the round fuselage *a* and tapered wing.—Figures 4, 5, and 6 present the polar characteristics of the tapered N. A. C. A. 0018–09 wing combined with the round fuselage in various vertical positions both with and without fillets. The low-wing, unfilleted combinations exhibited characteristic interference burbles occurring progressively earlier as the wing was moved downward. Fillets eliminated this condition but the increase in minimum drag, as the wing departs from the midwing position, that operated for the unfilleted combinations, held for the filleted combinations (table V). In the midwing and high-wing positions, fillets had very little effect except where an early interference burble at negative lifts produced an increase in the minimum drag. For such a combination, fillets served to reduce the minimum drag by eliminating the causative burble (fig. 4). Maximum lifts, as in most other combinations, were higher for the high-wing than for the low-wing positions whether or not the wing junctions were filleted.

The effect of a cowled engine at the nose of a tapered-wing combination is compared in figure 7 with a similar combination with a rectangular symmetrical wing. In the low-lift range, before the interference burble for the rectangular wing occurred, the effect for both wing shapes was practically identical. The tendency of a cowling toward suppressing the interference burble was evidently effective, and the polar curves for both cowled-engine combinations are virtually the same.

If the "speed-range index," the ratio of the maximum lift to a high-speed drag (see reference 1), be used as a criterion for comparing the combinations investigated in this report, the rectangular fuselage combined with the rectangular N. A. C. A. 4412 airfoil in a connected high-wing position would appear surprisingly good, inasmuch as it has one of the highest indexes of the combinations without high-lift devices investigated thus far. This combination does not have an exceptionally low drag coefficient, but the maximum lift coefficient is unusually high. If consideration be given, however, to the employment of various high-lift devices, the relative merit of the combinations may be changed and the minimum drag coefficient be shown to have much greater weight. Other favorable combinations in this report are the high-wing, rectangular-fuselage, tapered-wing combination and the midwing and semihigh-wing, round-fuselage, tapered-wing combinations with fillets.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *March 12, 1936.*

REFERENCES

1. Jacobs, Eastman N., and Ward, Kenneth E.: Interference of Wing and Fuselage from Tests of 209 Combinations in the N. A. C. A. Variable-Density Tunnel. T. R. No. 540, N. A. C. A., 1935.
2. Jacobs, Eastman N., and Abbott, Ira H.: The N. A. C. A. Variable-Density Wind Tunnel. T. R. No. 416, N. A. C. A., 1932.

TABLE I.—AIRFOIL CHARACTERISTICS

Airfoil	C_L	C_{D_0}	$C_{m_{c/4}}$	C_L	C_{D_0}	$C_{m_{c/4}}$	C_L	C_{D_0}	$C_{m_{c/4}}$
	$\alpha=0°$			$\alpha=4°$			$\alpha=12°$		
Rectangular N. A. C. A. 0012	0.000	0.0080	0.000	0.307	0.0087	0.003	0.920	0.0150	0.004
Tapered N. A. C. A. 0018-09	.000	.0093	.000	.305	.0099	.006	.910	.0146	.013
	$\alpha=-4°$			$\alpha=0°$			$\alpha=8°$		
Rectangular N. A. C. A. 4412	−0.006	0.0097	−0.089	0.298	0.0095	−0.087	0.899	0.0136	−0.084

TABLE II.—FUSELAGE CHARACTERISTICS

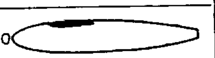
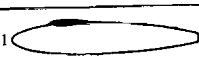
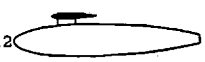
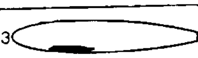
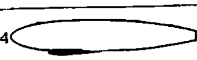
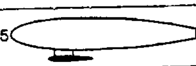
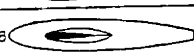
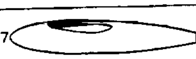
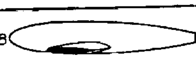
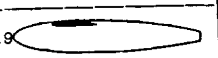
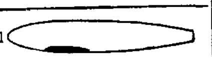
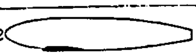
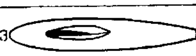
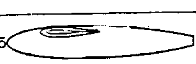
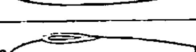
Fuselage	Engine	C_L	C_D	[1] C_{m_F}	C_L	C_D	[1] C_{m_F}	C_L	C_D	[1] C_{m_F}	C_L	C_D	[1] C_{m_F}	C_L	C_D	[1] C_{m_F}
		$\alpha=0°$			$\alpha=4°$			$\alpha=8°$			$\alpha=12°$			$\alpha=16°$		
Round	None	0.000	0.0041	0.000	0.001	0.0042	0.016	0.005	0.0049	0.028	0.011	0.0062	0.035	0.019	0.0085	0.038
Do	Uncowled	.000	.0189	.000	.001	.0191	.015	.004	.0200	.027	.008	.0216	.037	.015	.0244	.041
Do	Cowled	.000	.0069	.000	.008	.0073	.013	.017	.0088	.025	.028	.0115	.035	.040	.0165	.044
Rectangular	None	.000	.0049	.000	.005	.0054	.009	.014	.0068	.015	.026	.0097	.018	.040	.0151	.015

[1] Pitching-moment coefficient about the quarter-chord point of the fuselage.

TABLE III.—LIFT AND INTERFERENCE, DRAG AND INTERFERENCE, AND PITCHING MOMENT AND INTERFERENCE OF FUSELAGE IN WING-FUSELAGE COMBINATIONS

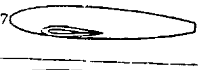
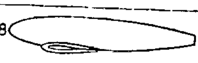
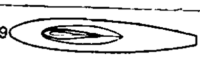
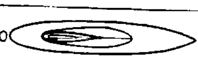
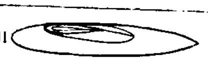
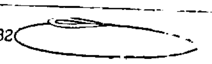
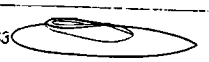
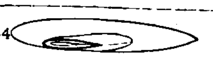
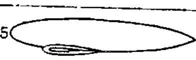
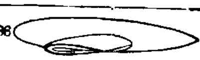
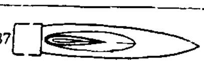
Combination	ΔC_L	ΔC_{D_0}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_0}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_0}	$\Delta C_{m_{c/4}}$
	$\alpha=0°$			$\alpha=4°$			$\alpha=12°$		
210	−0.009	0.0043	0.003	0.001	0.0046	0.007	0.033	0.0079	0.015
211	.014	.0045	.002	.026	.0045	.005	.058	.0087	.014
212	.002	.0055	.005	.009	.0057	.007	.033	.0073	.011
213	.013	.0044	−.003	.027	.0045	.002	.057	.0064	.004
214	−.014	.0045	−.002	.001	.0051	.002	−.047	.0368	−.012
215	−.002	.0055	−.005	.003	.0062	−.002	.009	.0083	−.004
216	−.009	.0042	−.002	.015	.0043	.005	.049	.0058	.009
217	−.015	.0045	.005	−.002	.0045	.009	.036	.0073	.015
218	.015	.0045	−.005	.035	.0042	−.001	.068	.0061	−.001
	$\alpha=-4°$			$\alpha=0°$			$\alpha=8°$		
219	−0.023	0.0037	−0.004	0.003	0.0034	0	0.038	0.0057	0.010
220	−.004	.0044	−.004	.018	.0036	0	.056	.0045	.009
221	−.019	.0048	−.010	−.002	.0044	−.005	.027	.0053	.002
222	−.025	.0050	−.012	−.010	.0045	−.006	.020	.0070	.002
223	−.027	.0049	−.006	−.006	.0043	−.002	.035	.0054	.011
224	−.006	.0039	−.005	.018	.0041	0	.053	.0050	.009
	$\alpha=0°$			$\alpha=4°$			$\alpha=12°$		
225	−0.006	0.0032	0.005	−0.001	0.0035	0.008	0.021	0.0064	0.019
226	.002	.0036	.004	.008	.0038	.008	.033	.0062	.015
227	.006	.0032	−.005	.024	.0034	−.003	.044	.0055	.002
228	−.002	.0036	−.004	.009	.0039	−.002	.017	.0081	.002
229	.003	.0033	−.002	.022	.0036	.004	.048	.0059	.011
230	.003	.0024	−.003	.023	.0024	.003	.042	.0040	.012
231	.022	.0031	0	.029	.0033	.002	.056	.0048	.010
232	.013	.0051	.007	.009	.0043	.011	.013	.0058	.025
233	.046	.0043	0	.054	.0048	0	.077	.0070	.004
234	.022	.0031	0	.001	.0032	.005	.024	.0044	.010
235	−.013	.0051	−.007	−.012	.0077	−.004	−.102	.0448	−.022
236	−.046	.0043	0	−.031	.0041	.001	−.017	.0053	−.001
237	.002	.0048	−.003	.025	.0055	.004	.055	.0117	.017

TABLE V.—PRINCIPAL AERODYNAMIC CHARACTERISTICS OF WING-FUSELAGE COMBINATIONS

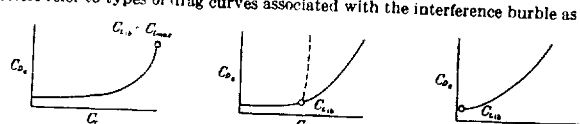
Diagrams representing combinations	Combination	Remarks	Longitudinal position d/c	Vertical position k/c	Wing setting i_w	Lift-curve slope (per degree) a A. R.=6.86	Span efficiency factor e	$C_{D_{e_{min}}}$	$C_{L_{opt}}$	Aerodynamic-center position n_0	C_{m_0}	Lift coefficient at interference burble [1] $C_{L_{ib}}$	[2] $C_{L_{max}}$ effective R. N.= 8.2×10^6	[2] $C_{L_{max}}$ effective R. N.= 3.7×10^6
Rectangular N. A. C. A. 0012 airfoil with rectangular fuselage														
	-----	Wing alone			*Degrees*	0.077	0.85	0.0080	0.00	0.010	0.000	[A] 1.5	[c] 1.54	[c] 1.39
210 	210		0.00	0.28	0	.080	.80	.0123	.00	.019	.003	[A] 1.3	[b] 1.33	[b] 1.31
211 	211		0	.34	0	.080	[3] .85	.0126	.07	.021	.001	[6] A 1.4	[c] 1.40	[c] 1.32
212 	212	Thin connecting plate (same as combination 149)	0	.54	0	.079	.85	.0135	.04	.016	.005	[A] 1.6	[c] 1.64	[c] 1.46
213 	213		0	−.28	0	.080	.85	.0123	.00	.021	−.003	[A] 1.4	[b] 1.41	[b] 1.39
214 	214		0	−.34	0	.080	[3] .80	.0126	−.07	.018	−.001	[B] .6	[c] 1.46	[c] 1.33
215 	215	Same as combination 212	0	−.54	0	.078	[3] .80	.0135	−.04	.018	−.005	[A] 1.6	[c] 1.60	[c] 1.46
216 	216	Tapered fillets	0	.00	0	.081	.85	.0121	.00	.024	.000	[A] 1.5	[c] 1.52	[c] 1.41
217 	217	do	0	.28	0	.081	[3] .80	.0122	−.03	.022	.005	[A] 1.3	[b] 1.30	[c] 1.33
218 	218	do	0	−.28	0	.082	.85	.0122	.03	.023	−.005	[A] 1.4	[c] 1.46	[c] 1.43
Rectangular N. A. C. A. 4412 airfoil with rectangular fuselage														
	-----	Wing alone				.076	.90	.0094	.22	.006	−.089	[A] 1.6	[a] 1.64	[a] 1.51
219 	219		0	0.26	0	.080	[3] .85	.0128	.30	.018	−.093	[A] 1.7	[a] 1.72	[a] 1.62
220 	220		0	.34	0	.080	[4] .90	.0131	.31	.018	−.093	[A] 1.6	[a] 1.68	[a] 1.57
221 	221		0	−.30	0	.080	[3] .85	.0139	.22	.021	−.098	[A] 1.6	[a] 1.67	[a] 1.57
222 	222		0	−.34	0	.080	[3] .85	.0142	.24	.022	−.101	[B] 1.2	[b] 1.67	[a] 1.57
223 	223	Tapered fillets	0	.00	0	.081	[3] .85	.0137	.29	.024	−.095	[A] 1.6	[b] 1.69	[b] 1.57
224 	224	Leading-edge fillets	0	.34	0	.080	[4] .90	.0133	.15	.018	−.093	[A] 1.6	[a] 1.67	[a] 1.60
Tapered N. A. C. A. 0018–0009 airfoil with rectangular fuselage														
	-----	Wing alone				.077	.90	.0093	.00	.020	.000	[A] 1.4	[c] 1.48	[c] 1.23
225 	225		0	0.22	0	.078	.85	.0124	.00	.030	.005	[A] 1.6	[c] 1.62	[a] 1.34
226 	226		0	.34	0	.078	.85	.0128	−.01	.027	.004	[A] 1.4	[a] 1.49	[a] 1.34

[1] Letters refer to types of drag curves associated with the interference burble. See footnote 1, p. 7.
[2] Letters refer to condition at maximum lift as follows: [a], reasonably steady at $C_{L_{max}}$; [b], small loss of lift beyond $C_{L_{max}}$; [c], large loss of lift beyond $C_{L_{max}}$ and uncertain value of $C_{L_{max}}$.
[3] Poor agreement in high-speed range.
[4] Poor agreement over whole range.
[5] Poor agreement in high-lift range.
[6] Rapid increase in drag preceding definite breakdown.

TABLE V.—PRINCIPAL AERODYNAMIC CHARACTERISTICS OF WING-FUSELAGE COMBINATIONS—Continued

Diagrams representing combinations	Combination	Remarks	Longitudinal position d/c	Vertical position k/c	Wing setting i_w	Lift-curve slope (per degree) a A. R.=6.86	Span efficiency factor e	$C_{D_{e\,min}}$	$C_{L_{opt}}$	Aerodynamic-center position n_0	C_{m_0}	Lift coefficient at interference burble [1] $C_{L_{ib}}$	[2] $C_{L_{max}}$ effective R. N.=8.2x10[6]	[2] $C_{L_{max}}$ effective R. N.=3.7x10[6]
Tapered N. A. C. A. 0018-0009 airfoil with rectangular fuselage—Continued														
227 	227		0	−.22	*Degrees* 0	.080	[4].90	.0124	.00	.027	−.005	[A] 1.5	[c] 1.51	[a] 1.27
228 	228		0	−.34	0	.079	[4].80	.0128	.01	.023	−.004	[B].9	[a] 1.26	[a] 1.10
229 	229	Tapered fillets	0	.00	0	.079	.85	.0127	.00	.030	.000	[A] 1.5	[c] 1.53	[a] 1.26
Tapered N. A. C. A. 0018-0009 airfoil with round fuselage														
230 	230	Tapered fillets	0	0.00	0	.080	[3].85	.0117	.00	.026	.000	[A] 1.5	[c] 1.52	[a] 1.27
231 	231	...do	0	.22	0	.079	[5].85	.0124	.00	.023	−.001	[A] 1.6	[c] 1.65	[a] 1.37
232 	232		0	.34	0	.076	.85	.0139	.17	.034	.006	[A] 1.6	[c] 1.61	[a] 1.31
233 	233	Tapered fillets	0	.34	0	.078	.85	.0135	−.07	.027	−.003	[A] 1.6	[c] 1.69	[a] 1.38
234 	234	...do	0	−.22	0	.080	[5].90	.0124	.00	.028	.001	[A] 1.4	[c] 1.48	[a] 1.22
235 	235		0	−.34	0	.076	[4].60	.0139	−.17	.028	−.006	[6B] .3	[c] 1.28	[a] 1.09
236 	236	Tapered fillets	0	−.34	0	.080	[3].90	.0135	.07	.024	.003	[A] 1.5	[c] 1.54	[a] 1.22
237 	237	Tapered fillets and cowled engine	0	.00	0	.080	.80	.0142	.00	.040	−.003	[6A] 1.5	[c] 1.53	[a] 1.28

[1] Letters refer to types of drag curves associated with the interference burble as follows:



[2] Letters refer to condition at maximum lift as follows: [a], reasonably steady at $C_{L_{max}}$; [b], small loss of lift beyond $C_{L_{max}}$; [c], large loss of lift beyond $C_{L_{max}}$ and uncertain value of $C_{L_{max}}$.

[3] Poor agreement in high-speed range.
[4] Poor agreement over whole range.
[5] Poor agreement in high-lift range.
[6] Rapid increase in drag preceding definite breakdown.

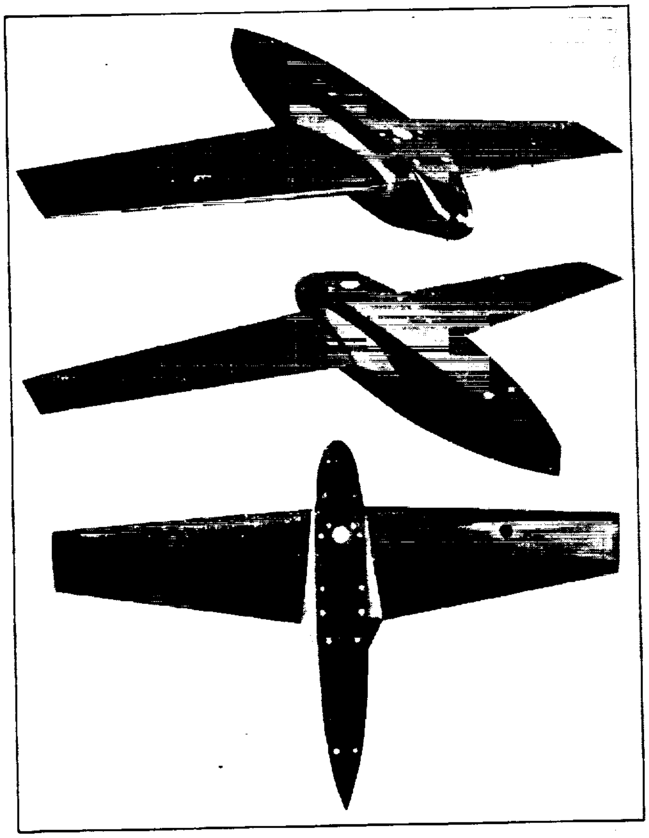


FIGURE 8.—Combination 229, showing tapered fillets.

FIGURE 9.—Combination 224, showing a leading-edge fillet in the shape of a windshield

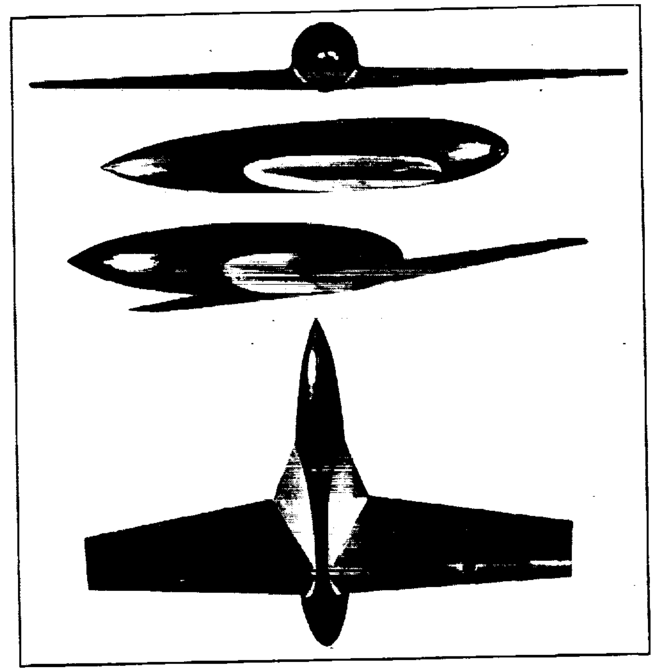


FIGURE 10.—Combination 234 (combination 231 inverted) showing tapered fillets.

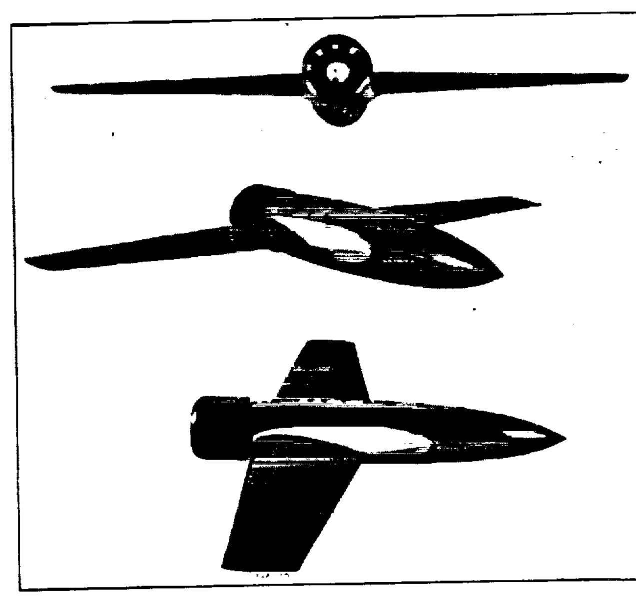


FIGURE 11.—Combination 237 showing a cowled engine and tapered fillets.

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